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SNS Front-End Systems Technical Note
FE3000
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MEBT Emittance Growth due to Quad Steering Correction

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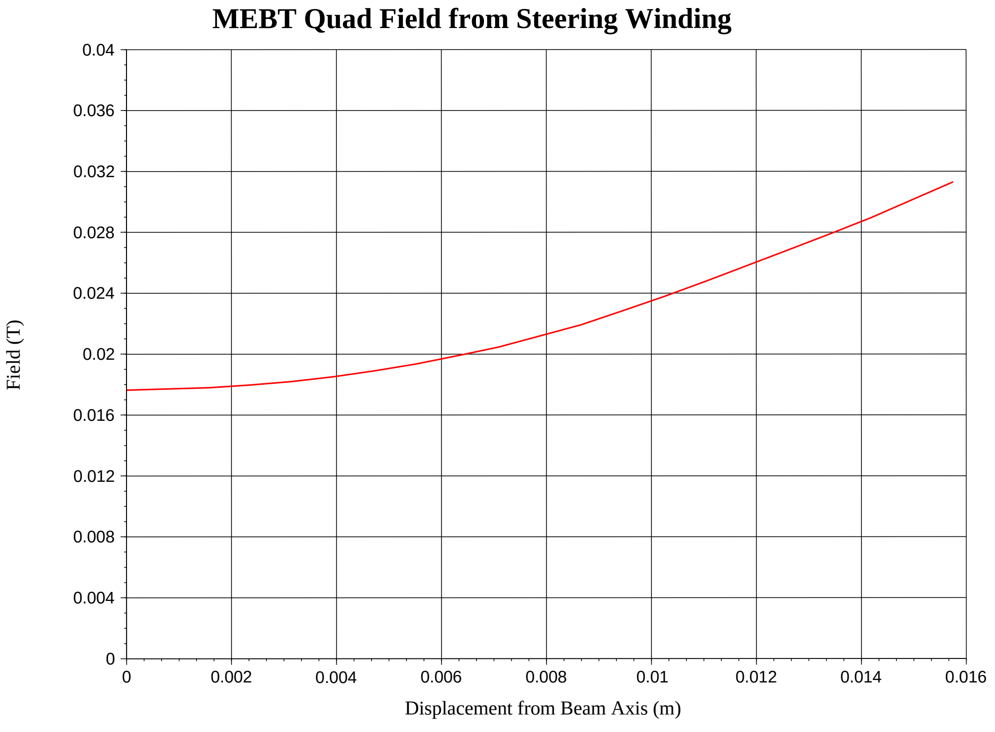
Steering correction in the MEBT will be included in six of the 14 quadrupoles. Backleg windings will introduce a dipole field on the beam axis, and as the pole tips are optimized for best quadrupole field, the dipole field will contain a large sextupole component.

The sextupole field component is a non-linear focusing field, and will contribute to emittance growth in the MEBT. We will estimate the magnitude of this growth.

Sextupole Magnitude

The magnitude of the dipole and sextupole components of the 1.5 cm aperture MEBT quadrupole has been determined by Daryl Oshatz and described in Front End Note FE-ME-013 (27 Aug 1999). The figure shows the calculated field for an excitation that produces a 175 Gauss dipole field at the origin.



A least-square analysis of the field distribution gives the following quadratic fit:

$$B(x) = 0.017539 + 0.0554\ x + 52.884\ x^2$$

where B is in Tesla and x in meters. The dipole field at the center is 0.0175 T (175 Gauss), the quadrupole field is small, and the sextupole field is given by the last term.

Note that this dipole correction field has been set at three times the value indicated in FE-ME-013, assuming the very worst case of misalignment implying a very large degree of steering correction.

The quality of the ANSYS calculation may be seen by noting that at a pole tip radius of 1.5 cm, the sextupole field component is 119 Gauss, added to the 175 Gauss dipole field, uniform across the aperture, and that the residual quadrupole field at 1.5 cm is only 7% of the sextupole component. (A perfect calculation would give no quadrupole field.) The actual quadrupole field, with the quadrupole winding excited is typically 3 kGauss.

Emittance Growth

To determine the emittance growth, the program TURTLE is used, which allows arbitrary multipoles to be included in quadrupoles. TURTLE is a macroparticle transport code like PARMILA, but does not include space charge. Therefore, the only source of emittance growth in TURTLE is focusing nonlinearity, from sextupole fields in this case.

Six of the 14 MEBT quadrupoles incorporate steering windings. Several TURTLE runs were made, with the above sextupole field applied to these six quadrupoles, but with various signs (all positive, all negative, and random signs) to simulate various steering conditions, but all at the same magnitude.

In addition, since the emittance growth is expected to scale as the square of the sextupole field, sextupole amplitudes of 3 times and 10 times the above value were also used to track the beam through the MEBT.

The effective length of the dipole and sextupole fields is assumed to be the same as the quadrupole effective length. While this is not strictly correct, the analysis below shows that this approximation should be acceptable.

Results

The TURTLE program expresses the emittance in unnormalized rms quantity in units of cm-mrad. The average value of the emittance of 0.32 pi cm-mrad corresponds to a normalized rms emittance of 0.023 pi cm-mrad, the value used in previous MEBT calculations.

The following table summarizes the TURTLE simulations, combining the results for several random choices of the signs of the sextupole fields distributed over the six quadrupole used for steering.

Sextupole Amplitude	x-emittance	y-emittance	x-growth	y-growth
None	0.3246	0.3224		
nominal	0.327	0.324	0.7%	0.5%
3 x nominal	0.357	0.337	10%	4.5%
10 x nominal	0.813	0.484	250%	150%

For the nominal sextupole amplitude (actually 3 times the value called for in FE-ME-013), the emittance growth is less than 1%. Three times this amplitude produces approximately 9 times the growth, and at 10 times nominal amplitude, the growth is more than 100 times, due to the beam size growing significantly in the MEBT and thereby experiencing the much large sextupole component at large radius.

Discussion

Even at steering values at three times the FE-ME-013 recommended values (the 3 times values are referred to above as "nominal"), the emittance growth is small, compared to the approximately 25% growth due to nonlinear space charge forces. With quadrupole alignment tolerances as specified in FE-ME-013, the steering corrections should be significantly smaller, and as the sextupole-induced emittance growth scales as the square of the steering corrections, the emittance growth due to the sextupole nonlinearity in the quadrupoles should be insignificant.